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OUTDOOR AND ACCELERATED WEATHERING OF  
ELASTOMERS AND PLASTICS: THE ASSESSMENT  
OF AN ACCELERATED WEATHERING TEST CHAMBER

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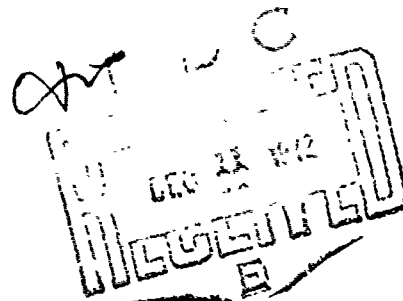
**EXPLOSIVES RESEARCH  
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TECHNICAL REPORT No. 107

**Outdoor and Accelerated Weathering of Elastomers  
and Plastics:  
The Assessment of an Accelerated Weathering  
Test Chamber**

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Outdoor and Accelerated Weathering of Elastomers  
and Plastics:  
The Assessment of an Accelerated Weathering  
Test Chamber

by

J Wright

SUMMARY

A range of elastomers and plastics were exposed in a 'Climatest' accelerated weathering test chamber which uses a fluorescent source of ultraviolet radiation. The rates of deterioration of the materials exposed in the 'Climatest' were compared with those of the same materials exposed out of doors at various sites including hot/wet and hot/dry tropical sites at JTRU Australia and temperate UK sites. The rates of deterioration obtained with the 'Climatest' were usually about ten times faster than outdoor tropical exposures, rather slower than had been anticipated. Correlation between the rates of change of mechanical properties of materials exposed in the 'Climatest' and out of doors was reasonably satisfactory, although visual failures apparent on specimens exposed out of doors were not necessarily reproduced by accelerated weathering cycles.

A brief description of the 'Climatest' and its operation is also given.

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Reference: WAC/220/05

## 1 INTRODUCTION

Of the many factors in the weather which contribute to the degradation of polymers, the principal influences are sunlight, water and temperature. The durability of polymeric materials is usually assessed either by exposure to natural weathering or in ageing trials conducted in the laboratory. However, to provide durability data more rapidly than is obtained in temperate climates, outdoor exposure trials are frequently made in the more rigorous climates of tropical areas. Nevertheless, lengthy periods of exposure may be necessary to obtain meaningful data on new materials.

In attempts to obtain weathering data after shorter periods of exposure out of doors, several approaches have been made which include:

- i Mirrors to concentrate solar radiation from sunlight on to specimens sometimes in conjunction with intermittent spraying with water<sup>1,2</sup> (Figure 1).
- ii Imposing stresses on the specimen.<sup>3-5</sup>
- iii Sensitive tests to determine changes in physical and/or chemical properties,<sup>6-13</sup> sometimes using thin polymer films.

An alternative approach is to expose specimens to artificial weathering cycles, which, provided that satisfactory correlation can be obtained with exposure out of doors, considerably reduces the period of exposure especially if used in conjunction with the techniques mentioned in ii and iii above.

The value of accelerated weathering as a technique for predicting the outdoor durability of polymers is a subject of much controversy, and its deficiencies are in part due to the variability of climatic conditions at outdoor exposure sites and the microenvironment of the specimen during exposure, together with the difficulty of reproducing sunlight with an artificial source of radiation.

Table 1 shows that the latter situation has improved in recent years with sources of radiation giving better correlation with sunlight than was possible hitherto with carbon-arc sources.<sup>14</sup>

TABLE 1

## ABSOLUTE ULTRAVIOLET INTENSITIES OF WEATHERING SOURCES AT SPECIMEN DISTANCE

Source	Total UV uW/cm	UV below 350 nm uW/cm	Ratio of UV < 350 nm: total UV
Sunlight (June) noon US	4 243	1 177	0.278
Sunlight (Dec) noon US	1 360	257	0.185
Xenon (1500 W)	5 474	1 340	0.245
Carbon arc ('sunshine')	8 486	1 386	0.163
Carbon arc	19 531	309	0.016
Fluorescent Sunlamp/Blacklamp	1 543	908	0.588
Sunlamp S-1	666	328	0.492

Hirt<sup>14</sup> suggests that the most suitable source of radiation for simulating sunlight is a high-pressure Xenon-arc; however, the radiation from this source (Figure 2) contains excess ultraviolet below 290 nm compared with sunlight and Pyrex glass filters are necessary in order to eliminate this low wavelength radiation. Such filters are subject to rapid solarization and it is essential to remove deposits from the water-cooled filter system otherwise fluctuations in light intensity occur. Fluorescent sunlamps\* on the other hand are deficient in short wave radiation but in combination with fluorescent blacklamps\* give a reasonably good approximation of terrestrial sunlight (Figure 3).

Accelerated weathering cycles which use fluorescent sunlamp/blacklamp combinations are claimed to have given satisfactory correlation with the outdoor weathering of transparent plastics.<sup>14,16</sup> In addition to giving a wavelength distribution superior to carbon-arc and mercury vapour sources (Figures 4-5)

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\*Fluorescent lamps constitute a means of converting ultraviolet light from a mercury discharge source into visible light by means of a phosphor inside the tube. The fluorescent sunlamp usually uses a thallium activated calcium phosphate phosphor and fluoresces in the ultraviolet from 260 - 400 nm and peaks at 320 nm. The fluorescent blacklamp uses a cerium activated calcium phosphate phosphor which emits in the range 350 - 400 nm and peaks at approximately 360 nm.

and not too dissimilar to sunlight, fluorescent lamps are operated at lower temperatures than carbon- or Xenon-arcs which will reduce the effects of heat on the materials undergoing examination.

A further advantage claimed for fluorescent sources of radiation is their relatively low maintenance costs. Furthermore their emission comes from a number of sources of large surface area, instead of a point source as with arc lamps, and the radiation may be maintained at a reasonable constant level by changing the lamps sequentially.

The main objectives of the present work were to assess a 'Climatest' accelerated weathering chamber supplied by Mectron Ltd, Slough, England, which uses a fluorescent source of radiation, and to compare the rates of deterioration of selected elastomers and plastics exposed in the Climatest with the rates obtained for the same materials after exposure at the hot/wet and hot/dry sites at JTRU Australia and UK temperate sites.

## 2 DESCRIPTION AND OPERATION OF 'CLIMATEST' APPARATUS

### 2.1 Description and Operation

The 'Climatest' environmental test apparatus (Figure 6) comprises the following main components.

- i A stainless steel test cabinet  $0.765 \text{ m}^3$  which contains the source of ultraviolet radiation and the specimens under test mounted on racks which move around the lamps at 1.0 rev/min.
- ii A conditioning chamber from which air of the required temperature and humidity is passed into the test cabinet.
- iii A unit containing temperature and humidity controls, power supply and related circuitry.

The test specimen capacity of the machine is either 800 ERDE dumb-bells<sup>17</sup> or 78  $150 \times 100 \text{ mm}$  plaques with other sizes in proportion. This capacity is considerably greater than that usually found in weathering chambers which use a Xenon arc source of radiation.

Air temperature may be varied between 15 and  $50^\circ\text{C}$  either by passing air over a refrigeration unit or a series of three 1 kW heaters, which are situated in the conditioning chamber. Temperature is controlled by a manually set indicator/control unit coupled to a platinum resistance bulb sensor at the point of entry of the air into the test cabinet.

Humidity may be varied between 45 and 100 per cent relative humidity by the introduction of water onto a spinning disc to produce small droplets which vaporise in the air stream. Humidity is controlled by wet and dry bulb resistance sensors.



An indication of the degree of control of temperature and humidity achieved with the Climatest through the day and from day to day is given below.

DAILY DATA FOR HOT DRY CYCLE (42°C 50% rh)

Time (h)	Temperature (°C)	Relative Humidity (per cent)
00.15	44	56
03.15	43	49
06.20	42.5	52
09.30	42	53
12.20	43	49
14.35	43	53
17.30	46	52
20.25	44	52

DAY TO DAY DATA FOR HOT/DRY CYCLE (42°C 50% rh) AT 0900 HOURS

Day	Temperature (°C)	Relative Humidity (per cent)
1	40	51
3	39	45
5	44	52
9	41	47
14	44	52
19	44	50
21	43	52
24	43	49

DAILY DATA FOR HOT/WET CYCLE (40°C 95% rh)

Time (h)	Temperature (°C)	Relative Humidity (per cent)
00.15	40	95
03.25	40	94
06.45	39	95
09.45	38.5	95
12.50	38.5	94
14.35	40	94
17.30	41	96
20.25	41	95

DAY TO DAY DATA FOR HOT/WET CYCLE (40°C 95% rh)

Day	Temperature (°C)	Relative Humidity (per cent)
1	40	94
3	40.5	90
5	51.5	91
7	43.5	88
9	40.5	90
11	41.5	91
13	42.5	89
15	40	95

In spite of fluctuations in ambient conditions it was found that control of temperature to  $\pm 3^{\circ}\text{C}$  and humidity to  $\pm 5\%$  could generally be achieved, and even closer control could be obtained by the use of exhaust flaps and movable vents situated at the back and at the top of the weathering chamber. For future work the apparatus is being relocated in a room equipped with thermostatically controlled temperature equipment, where improved control over temperature and humidity will be possible.

With respect to lower temperatures, the temperatures recorded during a typical cold/dry cycle using the refrigeration unit are given below.

h	$^{\circ}\text{C}$
09.00	10.5
11.00	13.5
13.00	13.5
14.00	12.5
14.30	11.5

Rainfall, if required, is simulated by the use of a water spray consisting of 'fan-jet' nozzles mounted on a manifold positioned to give a fine water spray over all the specimen area. Water required for spraying or humidifying the air is pumped from a supply tank into the conditioning chamber as required. During the present investigation the consumption of water was found to average about 32 litres (7 gallons) per day. For the present investigation distilled deionized water was fed into the tank as required.

Ultraviolet radiation is supplied by 32 fluorescent discharge tubes assembled around the periphery of a centrally positioned drum. The lamps are electrically connected as 16 pairs of sunlamps TL20/W12 and blacklamps TL20/O8. The lamps can be switched off by hand or by the programme mechanism individually or totally to simulate dark periods. It has been shown<sup>10</sup> by using chemical actinometry methods that the level of radiation from the lamps diminishes continuously, the light intensity of a new set of lamps after 15 and 52 hours being reduced by 13 per cent and 24 per cent respectively. 18 Per cent of the total incident radiation is reflected on to the backs of the specimen by the walls of the cabinet. To ensure that all the specimens received a reasonably constant level of radiation throughout the exposure period one pair of lamps were changed every 168 hours throughout the period of the present investigation.

A number of minor practical operational difficulties which have been encountered with the Climatest apparatus are summarized below; most of these have now been rectified locally.

- i Disintegration of plastic covers on lampholder brackets.

- ii Difficulty in cleaning the water filter.
- iii Low capacity of water storage tank and difficulty in cleaning tank.
- iv Retention of excess water on floor of chamber due to low camber of chamber floor.
- v Lack of screening of vent and exhaust flaps allowing insects to enter chamber which are then washed into water storage tank with subsequent blocking of water sprays and contamination of water.
- vi Relative inaccessibility of programme mechanism, heater controls, exhaust flaps and controls which should be capable of being operated from the front of the apparatus.

## 2 2 Effect of Position of Polyurethane Elastomers in the Climatest on their Rates of Deterioration

It is possible that the fluorescent tubes in the Climatest do not emit a constant level of radiation along the whole 600 mm of their length. Therefore a preliminary investigation was made to determine if any differences occurred in the rates of deterioration of a polyurethane elastomer mounted in different positions relative to the length of the tubes.

Sheets 150 × 100 mm, 1.0 mm thick of a clear polyether urethane elastomer based on a commercial poly 1,4-oxybutylene glycol/toluene diisocyanate pre-polymer cured with 4,4'-methylene bis(2-chloroaniline) (95 per cent stoichiometric), which discolours when exposed to ultraviolet light, were exposed for periods of up to 1000 hours in the Climatest using a hot/dry cycle at 33°C, 50 per cent relative humidity. The specimens were mounted at the same distance from, but in different positions along the 600 mm length of the tube, i.e., 100 - 200 mm (top), 250 - 350 mm (middle), 400 - 500 mm (bottom), thus avoiding the exposure of specimens opposite the extremities of the fluorescent tubes.

After selected periods of exposure the specimens were examined visually for changes in colour and by ultraviolet spectroscopy for changes in optical density in the region of 400  $\mu\text{m}$  (preliminary readings taken in the 380 - 400  $\mu\text{m}$  region showed that the minimum optical density occurred at 385  $\mu\text{m}$  and this wavelength was used for all determinations). Changes in moduli were measured on dumb-bell specimens cut from the weathered sheets of elastomer, determined on a Hounsfield Type E Tensometer at a constant rate of extension of 500 mm/min by British Standard methods.<sup>19,20</sup> The results summarized in Table 2 below indicate that the position of mounting specimens relative to the length of the fluorescent tubes, provided that exposures opposite the ends of the tubes are avoided, is unlikely to produce significant differences in the rates of deterioration of polyurethane elastomers during exposure to accelerated weathering cycles in the Climatest. With other types of polymer, however, the differences may be more significant.

TABLE 2

Position in Climate test chamber with respect to Fluorescent Tube	Period of Exposure (Hours)	Colour (Visual)	Optical Density (396 $\mu\text{m}$ )	Modulus ( $\text{MN}/\text{m}^2$ ) at extensions of		
				100 (per cent)	200 (per cent)	300 (per cent)
Control	Not exposed	Pale lemon	0.52	5.7	8.8	13.4
Top	250	Yellow	1.27	5.8	8.3	12.7
Centre	250	Yellow	1.32	6.1	8.9	14.2
Bottom	250	Yellow	1.32	5.2	7.9	12.7
Top	500	Deep yellow	1.74	5.1	8.0	12.4
Centre	500	Deep yellow	1.72	5.3	8.2	13.1
Bottom	500	Deep yellow	1.52	5.6	8.4	13.0
Top	1000	Amber	>2.0	4.6	7.2	11.0
Centre	1000	Amber	>2.0	4.5	7.2	11.1
Bottom	1000	Amber	>2.0	4.8	7.2	11.2

### 3 ASSESSMENT OF ELASTOMERS

#### 3 1 Selection of Elastomers

A series of newer types of elastomers and polyester and polyether urethane elastomers which have been or are being exposed at JTRU Australia and UK\* exposure sites, were selected for assessment in the Climate test. Brief details of the materials are given below. (A series of high performance polyurethane elastomers were also exposed but the results of that investigation will be the subject of a separate report.)

Elaprim E152 (polyacrylate) 100 parts, Philblack A carbon black 50 parts	(CODE ALE)
Elaprim E153 (polyacrylate) 100 parts, Philblack A carbon black 50 parts	(CODE AHE)
Herchlor C (epichlorhydrin/ethylene oxide copolymer, 100 parts, Philblack A carbon black 50 parts	(CODE EC)
Herchlor H (polyepichlorhydrin) 100 parts, Philblack A carbon black 50 parts	(CODE EH)
Silastic LS63 (fluorosilicone copolymer) unfilled	(CODE F)
Hypalon (chlorosulphonated polyethylene) 100 parts, titanium dioxide 20 parts	(CODE HW)
Hypalon (chlorosulphonated polyethylene) 100 parts, Philblack A carbon black 10 parts	(CODE HB)
Silastomer ESP 2811 (silicone) unfilled	(CODE S)
Commercial polyester urethane containing carbon black	(CODE PU 1)
Commercial polyether urethane containing carbon black	(CODE PU 2)
Laboratory prepared polyester urethane containing 4 per cent polycarbodiimide, unfilled	(CODE PU 3)

Details of the formulations of most of the elastomers and their methods of preparation have been given elsewhere.<sup>21</sup>

#### 3 2 Exposure and Methods of Test

The elastomers were exposed as sheets 150 mm x 100 mm approximately 2.5 mm thick, to the various accelerated weathering cycles listed below. The average daily mean climatic conditions prevailing at the JTRU hot/wet cleared and hot/dry sites (Figures 7 - 8) were used as a rough guide in selecting the temperatures and humidities used in the Climate test chamber.

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\*ERDE Waltham Abbey

- Cycle 1 Hot/wet. 500 hours at 28°C, 95 per cent relative humidity; during each period of 2 hours the lamps were switched off for 5 minutes and the specimens sprayed with deionized distilled water.
- Cycle 2 Hot/wet. 1000 hours; 500 hours as cycle 1 above, plus 500 hours at 33°C, 95 per cent relative humidity; during each period of 2 hours the lamps were switched off for 10 minutes and the specimens sprayed with deionized distilled water.
- Cycle 3 Hot/dry. 500 hours at 33°C, 50 per cent relative humidity; during each period of 2 hours the lamps were switched off for 1 minute and the specimens sprayed with deionized distilled water.
- Cycle 4 Hot/dry. 1000 hours as cycle 3 above.

After the required periods of exposure five ERDE dumb-bell test pieces were cut from each of the elastomer sheets and conditioned for 24 hours at 21°C, 65 per cent relative humidity. Hardness was measured using a microindenter and tensile properties at a constant rate of extension of 500 mm/min by British Standard Methods.<sup>19,20</sup> Unaged control specimens cut from the materials were tested by the same methods and the results used as unaged reference points.

The results summarized in Table 3 compare the results obtained for the elastomers after accelerated weathering cycles with those obtained from outdoor exposures at JTRU and the UK temperate site at Waltham Abbey.

### 3.3 Summary of Results

#### 3.3.1 Newer Elastomers

The behaviour of the elastomers to natural and accelerated weathering can for convenience be divided into three groups.

The first group, the two acrylate and two epichlorhydrin elastomers, containing 33 per cent carbon black, showed little change either visually or in mechanical properties, apart from slight increases in tensile strength, moduli and hardness with losses of extension at break of up to 15 - 20 per cent.

The second group, the unfilled silicone and fluorosilicone elastomers, were relatively unaffected by weathering, apart from small losses of tensile strength, moduli and hardness, especially under hot/wet conditions.

The third group, the black and white filled Hypalon elastomers, showed significant changes in mechanical properties, with only small increases in tensile strength, but with substantial increases in moduli and hardness coupled with losses of extension at break of 25 to 40 per cent.

The overall acceleration factor for the rate of breakdown of elastomers exposed in the Climatest does not to exceed 9:1 compared with short term tropical exposures or about 18:1 compared with temperate exposures; however, elastomers exposed in the Climatest stiffened at faster rates than these factors indicate as shown by their increases in moduli and hardness. All the elastomers, with the possible exception of the Hypalons, which seem likely to embrittle during long term outdoor exposure, are high performance materials and likely to give relatively good durability out of doors.

In general although the observed changes both out of doors and in the Climatest were small, the changes in properties were in the same direction with satisfactory correlation between natural and accelerated ageing.

### 3 3 2 Polyurethane Elastomers

The degree of correlation obtained between the performances of a black filled and clear polyester urethane elastomer containing 4 per cent polycarbodiimide after 1000 hours' hot/wet exposure in the Climatest compared with 2 years' hot/wet outdoor tropical exposure at the JTRU cleared site was satisfactory. The black filled polyester urethane showed comparatively little deterioration on either exposure compared to the severe losses of tensile strength which occurred with the clear polyester urethane elastomer containing 4 per cent polycarbodiimide during both natural and accelerated weathering.

The black filled polyether urethane elastomer was severely degraded at the hot/wet cleared JTRU site after 4 years' exposure, as shown by considerable loss of tensile strength. The only deterioration in this elastomer apparent after 1000 hours' hot/wet Climatest exposure was a loss of 100 per cent modulus similar to that which occurred out of doors.

## 4 PLASTICS

The following plastics which are being or have previously been exposed out of doors were selected for assessment by accelerated weathering cycles in the Climatest apparatus.

### I Glass reinforced polypropylene thermoplastics

- Type 1 Polypropylene PXC 8639 60 per cent, Glass MSS 1607 40 per cent
- Type 2 Polypropylene PXC 8639 60 per cent, Glass MSS 1613 40 per cent
- Type 3 Polypropylene PXC 8639 60 per cent, Glass MSS 1607 40 per cent, Vulcan XXX\* carbon black 1.5 per cent

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\*by weight on polypropylene



Type 4 Polypropylene PXC 8639 60 per cent, Glass MSS 1613 40 per cent, Vulcan XXX\* carbon black 1.5 per cent.

Type 5 Polypropylene PXC 8639 60 per cent, Glass MSS 1607 40 per cent, Dye Oil Nigrosine\* 0.5 per cent.

Type 6 Polypropylene PXC 8639 60 per cent, Glass MSS 1613 40 per cent, Dye Oil Nigrosine\* 0.5 per cent.

II Acetal Copolymer 'Alkon' M90-02 (0.10), Unpigmented

III Chlorinated Polyether, Penton 9215J, Unpigmented

In an attempt to accelerate the breakdown of the plastics specimens at a greater rate than was obtained for the elastomers described in the previous section, the conditions selected for weathering in the Climatest were based on the average maximum temperatures at the JTRU hot/wet and hot/dry tropical sites (Figures 7 - 8). ERDE injection moulded dumb-bell test specimens of the selected plastics in sets of five per withdrawal were exposed to the following accelerated weathering cycles.

Cycle 5 Hot/wet. 500 hours at 35°C, 95 per cent relative humidity; during each period of 2 hours the lamps were switched off for 10 minutes and the specimens sprayed with distilled deionized water.

Cycle 6 Hot/wet. 1000 hours as cycle 5 above.

Cycle 7 Hot/dry. 500 hours at 42°C, 50 per cent relative humidity. No dark periods or water spraying.

Cycle 8 Hot/dry. 1000 hours as Cycle 7 above.

After the required periods of exposure the specimens and controls were tested for tensile properties at a constant rate of extension of 25 mm/min by British Standard Methods.<sup>19, 20</sup>

For convenience the results are discussed under three main headings.

I Glass reinforced polypropylene. Climatest exposures are compared with outdoor exposures at a UK temperate site at ERDE Waltham Abbey. The results are summarized in Table 4.

II Acetal copolymer. Climatest exposures are compared with exposures to

a EMMA (an outdoor solar radiation concentrating device at a hot/dry site in Arizona<sup>22</sup>)

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\*by weight on polypropylene

- b Outdoor static exposures at a hot/dry site, Arizona
- c Outdoors, hot/wet tropical cleared, JTRU, Australia<sup>23</sup>
- d Outdoors, hot/dry tropical, JTRU, Australia<sup>23</sup>
- e Outdoors, temperate, UK site (RAE Farnborough)<sup>23</sup>

III Chlorinated Polyether (Penton) Climate test exposures are compared with exposures at

- a Outdoors, hot/wet cleared tropical, JTRU, Australia<sup>24</sup>
- b Outdoors, hot/dry tropical, JTRU, Australia<sup>24</sup>

The results for acetal copolymer and Penton are summarized in Tables 5 - 6 but because of differences in the methods of test, rates of straining, tensile testing machines and methods of conditioning the specimens, the results for these materials are discussed by comparing the percentage changes in their original mechanical properties.

#### 4 1 Glass Reinforced Polypropylene Thermoplastics

The results of natural and accelerated weathering exposures recorded in Table 4 show that the rates of deterioration as shown by changes in original mechanical properties, after 500 hours' exposure to hot/wet or hot/dry conditions in the Climate test were similar to those obtained after 6 months' temperate UK outdoor exposure. Glass reinforced polypropylene containing either 1.5 per cent carbon black or 0.5 per cent oil nigrosine dye was superior to unfilled or undyed glass reinforced polypropylene. Similarly, carbon black was more effective than nigrosine in protecting glass reinforced polypropylene from degradation.

Glass reinforced polypropylene without additives lost about 66 per cent of its initial tensile strength and 50 per cent extension at break, and showed severe discolouration and erosion during exposure to accelerated weathering cycles. Glass reinforced polypropylene containing 0.5 per cent nigrosine lost about 20 per cent of its initial tensile strength and extension at break and showed definite erosion during exposure to accelerated weathering, whilst glass reinforced polypropylene containing 1.5 per cent carbon black showed relatively small losses of original tensile strength and extension at break of 5 per cent and 15 per cent respectively and showed only slight erosion.

Glass reinforced polypropylene without any additives exposed in the Climate test was more readily degraded under hot/dry than under hot/wet conditions; however with glass reinforced polypropylene containing carbon black or nigrosine there was no significant difference between the effects of either condition.

Visual failures, for example discolouration and erosion, were more severe on specimens exposed to accelerated weathering cycles than on those exposed to natural weathering, although glass reinforced propylene containing nigrosine was showing signs of erosion between 3 and 6 months' outdoor exposure. The increase in tensile strength of Type 2 after 3 months' outdoor exposure, followed by a drop in tensile properties after 6 months' exposure, cannot be readily accounted for.

#### 4 2 Acetal Copolymer

Acetal copolymer specimens showed considerable embrittlement during weathering in the selected environments, as shown by the considerable reductions of original extensions at break, which were usually accompanied by significant losses of tensile strength. In addition, the specimens showed changes of colour, chalking, erosion and/or cracking when assessed visually.

Specimens exposed to hot/dry and hot/wet accelerated weathering cycles in the Climatest showed the greatest change of original mechanical properties during the first 500 hours' exposure, showing losses of original extensions at break of 83 to 95 per cent respectively. During this period the specimens showed loss of gloss and yellowing followed by the development of a hard firmly adherent white coating on the exposed surfaces which appears to have prevented further degradation of the underlying material during weathering periods beyond 500 hours. To a lesser extent a similar effect was noted with specimens exposed for between 6 months and 2 years at the hot/wet cleared JTRU site and between 3 months and 1 year at the temperate UK site where tensile strengths showed little or no change.

At all the outdoor sites, however, including the EMMA solar radiation concentrating device, all the specimens showed chalking and cracking, whilst with specimens exposed to accelerated weathering cycles in the Climatest the only evidence of cracking was on the non-exposed reverse faces of the specimens which receive considerably less ultraviolet radiation than the surfaces directly exposed to radiation. Specimens exposed out of doors to EMMA and at the hot/wet cleared site at JTRU showed the most rapid losses of tensile strength. Specimens exposed to accelerated weathering cycles showed the most rapid losses of extension at break; correlation of this property between Climatest accelerated weathering exposures and outdoor exposures was particularly satisfactory.

An indication of the relative acceleration factors can be deduced from the information summarized below.

Changes in Original Mechanical Properties after Exposure to								
Days' Exposure	Climate test (Hot/dry)			EMMA Arizona (hot/dry)		Arizona (Hot/dry)		JTRU (Hot/dry)
	Tensile Strength	Extension at Break	Tensile Strength	Extension at Break	Tensile Strength	Extension at Break	Tensile Strength	Extension at Break
21-28	-13	-83	-18.5	-66.5	-41.0	-83.0	-17.0	-68.0
42-56	-14	-83	-46.5	-69.0			-49.0	-87.0
100-112			-86.5	-89.0				
1000								
Days' Exposure	Climate test (Hot/wet)			JTRU (Hot/wet)		UK (Temperate)		
	Tensile Strength	Extension at Break	Tensile Strength	Extension at Break	Tensile Strength	Extension at Break		
21	-47.0	-95.5						
42	-26.5	-90.0						
100-112			-37.0	-87.0	-7.5	-53.5		
1000			-82.5	-93.5	-45.0	-93.0		

The acceleration factor of the Climatest for acetal copolymer is of the order of 5-6:1 compared to outdoor exposure at the JTRU tropical sites and roughly the same rates of deterioration are obtained with the Climatest as with the EMMA solar radiation concentrating device. Both these methods give an acceleration factor of as much as 20:1 for acetal copolymer compared to temperate UK exposures.

#### 4.3 Chlorinated Polyether 'Penton'

During exposure to natural and accelerated weathering the Penton specimens showed a tendency to embrittle. This was manifest by considerable losses of extensions at break and moderate increases in tensile strength. Specimens exposed out-of-doors during the earlier stages of exposure (3 - 6 months) showed losses of tensile strength but on further exposure this trend was reversed and increases of original tensile strength occurred. This usually coincided with loss of ductility in the material. Although this effect was not recorded with specimens exposed to hot/dry accelerated weathering cycles in the Climatest, similar changes occurred during hot/wet Climatest exposures between 500 and 1000 hours. Apart from severe yellowing of the specimens, Climatest exposure failed to produce the same types of breakdown which were apparent on visual inspection of the specimens exposed out-of-doors, which included severe erosion and chalking. However, judged solely on the rates of change of mechanical properties the correlation between accelerated and outdoor weathering was satisfactory. The acceleration factor of the accelerated weathering cycles in the Climatest compared to exposure at hot/wet and hot/dry sites at JTRU was of the order of 10:1.

#### 5 DISCUSSION AND CONCLUSIONS

The Climatest accelerated weathering chamber appears to be a useful additional method for studying the weathering characteristics of polymers. The equipment is of value for assessing formulation variables, for example the effect of additives, and for the preliminary screening of new materials prior to exposure at JTRU (Australia), thus avoiding the expense of exposing unsatisfactory materials. The Climatest is capable of simulating both hot/wet and hot/dry environments and when used in conjunction with more sensitive physical<sup>10</sup> and/or chemical<sup>11</sup> methods of test, should enable predictions of polymer durability during long term outdoor weathering to be made after relatively short periods of exposure.

The rates of deterioration obtained with accelerated weathering cycles in the Climatest were rather slower than had originally been anticipated, although the degree of correlation with outdoor exposure, shown by changes in mechanical properties, was reasonably satisfactory. Correlation between visual failures however were not always as satisfactory. Faster rates of deterioration might be achieved if the Climatest was operated at its maximum operating temperature (58°C).

The acceleration factor obtained with hot/wet and hot/dry cycles in the Climatest based on the limited range of materials examined so far, was approximately 10:1 compared with hot/wet and hot/dry outdoor exposures at JTRU and about 20:1 compared with UK temperate exposure.

No attempts are made in the present investigation to draw any direct conclusions based on comparisons between ultraviolet radiation received by the specimens during natural and accelerated weathering as insufficient information is at present available concerning the distribution of ultraviolet radiation at specific wavebands. However a crude comparison of total radiation is given below.

	Radiation per year (h)	Sun hours per year
UK temperate <sup>26</sup>		1400
JTRU Innisfail Hot/wet cleared		2400
JTRU Cloncurry Hot/dry		3650
Climatest Hot/dry cycle (no dark periods)	8750	
Climatest Hot/wet cycle (water spraying and dark period 10 minutes per 2 hours)	8030	

Similarly, Table 1 shows that the proportion of ultraviolet radiation below 350 nm, usually acknowledged to be the most destructive towards polymers in the Climatest, is about  $2\frac{1}{2}$  times that present in sunlight over a 12 month period. However, additional stresses imposed on materials during exposure by changes and fluctuations in temperature and relative humidity, rainfall and abrasion, coupled with microbiological attack make comparisons between natural and accelerated weathering more difficult.

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TABLE 3

## OUTDOOR AND ACCELERATED WEATHERING OF ELASTOMERS

Elastomer Type	Type of Exposure and Duration (Days)	Tensile Strength (MN/m <sup>2</sup> )	Extension at Break (per cent)	Modulus (MN/m <sup>2</sup> ) at extensions of			Hardness (B <sub>50</sub> )	Visual assessments Major type of failure (0) = no change (4) = severe change
				100 (per cent)	200 (per cent)	300 (per cent)		
Acrylate AIE (Black)	Control (not exposed)	10.6	230	2.5	9.2	-	65	
	21 Hot/wet Climtest	12.1	225	3.2	10.7	-	76	(0)
	42 Hot/wet Climtest	11.0	195	3.4	-	-	71	(0)
	180° Hot/wet cleared JTRU	11.1	210	4.5	13.4	-	53	
	360° Temperature UK	10.6	230	2.5	9.3	-	63	(0)
	21 Hot/dry Climtest	10.3	220	2.4	9.3	-	71	(0)
Acrylate AHE (Black)	42 Hot/dry Climtest	11.4	230	2.6	9.4	-	73	(0)
	180° Hot/dry JTRU	11.4	200	2.9	11.2	-	51	
	Control (not exposed)	12.6	220	2.9	10.5	-	66	(0)
	21 Hot/wet Climtest	12.5	225	4.0	11.9	-	69	(0)
	42 Hot/wet Climtest	13.1	210	4.0	12.6	-	77	(0)
	180° Hot/wet cleared JTRU	13.8	220	4.0	11.2	-	68	
Epichlorohydrin EII nonopolymer (Black)	360° Temperature UK	12.1	225	4.3	10.3	-	73	(0)
	21 Hot/dry Climtest	12.7	245	4.0	10.0	-	70	(0)
	42 Hot/dry Climtest	12.4	225	4.0	10.7	-	71	(0)
	180° Hot/dry JTRU	12.0	225	4.2	10.6	-	63	
	Control (not exposed)	10.7	410	2.9	7.4	9.0	90	Loss of gloss (1)
	21 Hot/wet Climtest	10.5	320	2.8	8.1	10.5	90	Loss of gloss (1)
Epichlorohydrin EC copolymer (Black)	42 Hot/wet Climtest	10.5	330	2.7	7.9	9.7	96	Loss of gloss (1)
	180° Hot/wet cleared JTRU	11.1	360	3.9	8.1	10.5	93	Loss of gloss (1)
	360° Temperature UK	10.5	380	3.9	7.6	8.0	56	Dirt collection (1)
	21 Hot/dry Climtest	10.1	375	2.3	8.4	10.1	82	Loss of gloss (1)
	42 Hot/dry Climtest	10.5	345	4.8	8.5	10.3	89	Loss of gloss (1)
	180° Hot/dry JTRU	10.6	375	3.7	7.6	10.4	82	Loss of gloss (1)
20.1 Epichlorohydrin EC copolymer (Black)	Control (not exposed)	11.5	290	2.5	6.3	-	79	Loss of gloss (1)
	21 Hot/wet Climtest	13.4	335	3.4	8.7	12.7	78	Loss of gloss (1)
	42 Hot/wet Climtest	13.0	320	2.4	8.8	12.7	88	Loss of gloss (1)
	180° Hot/wet cleared JTRU	12.3	340	1.9	7.8	11.7	78	Loss of gloss (1)
	360° Temperature UK	11.7	400	1.9	5.8	9.6	75	Cracking (1)
	21 Hot/dry Climtest	13.0	325	3.3	8.4	12.4	82	Loss of gloss (1)
20.1 Epichlorohydrin EC copolymer (Black)	42 Hot/dry Climtest	13.0	330	2.2	8.1	12.2	81	Loss of gloss (1)
	180° Hot/dry JTRU	12.1	325	2.8	7.7	11.6	75	Loss of gloss (1)

Out of doors  
\*6 months  
\*\*12 months

10.2

10.3



TABLE 3 (contd)

Elastomer Type	Type of Exposure and Duration (Days)	Tensile Strength (N/m <sup>2</sup> )	Extension at Break (per cent)	Modulus (N/m <sup>2</sup> ) at extensions of			Hardness (BS°)	Visual assessments Major type of failure (0) = no change (4) = severe change
				100 (per cent)	200 (per cent)	300 (per cent)		
Fluorosilicone (Clear) F	Control (not exposed)	6.2	160	3.1	-	-	72	
	21 Hot/wet Climate	5.5	145	3.1	-	-	72	(0)
	42 Hot/wet Climate	5.6	155	2.9	-	-	78	(0)
	100° Hot/wet cleared JTRU	5.7	160	2.5	-	-	64	
	360° Temperate UK	5.8	165	2.9	-	-	64	Dirt collection (1)
	21 Hot/dry Climate	6.6	180	3.1	-	-	75	(1)
	42 Hot/dry Climate	6.7	165	3.5	-	-	78	(2)
Silicone S (Clear)	180° Hot/dry JTRU	5.4	165	2.3	-	-	63	
	Control (not exposed)	8.6	520	1.1	2.7	4.5	65	
	21 Hot/wet Climate	6.7	460	1.1	2.7	4.6	63	(0)
	42 Hot/wet Climate	5.5	430	0.9	2.1	4.9	72	Discolouration (1) surface haze
	100° Hot/wet cleared JTRU	6.0	450	0.7	2.1	3.7	62	
	360° Temperate UK	7.0	430	1.0	2.7	4.5	62	Dirt collection (1)
	21 Hot/dry Climate	6.9	515	2.1	3.6	5.1	67	(2)
Hypalon HW (White)	42 Hot/dry Climate	6.1	490	2.0	3.5	5.0	69	(0)
	180° Hot/dry JTRU	7.3	490	0.7	2.2	3.8	61	
	Control (not exposed)	14.0	435	3.5	8.5	11.7	67	
	21 Hot/wet Climate	12.6	290	6.1	10.0	-	85	Discolouration (3) pink stain underside
	42 Hot/wet Climate	14.1	295	7.5	10.9	-	95	Discolouration (3) pink stain underside
	180° Hot/wet cleared JTRU	15.7	335	6.2	9.7	14.5	87	Discolouration (3) pink stain underside
	360° Temperate UK	14.0	325	5.0	8.3	13.4	80	Chalking (1)
Out of doors 6 months 12 months 21.1	21 Hot/dry Climate	14.9	220	8.1	14.2	-	83	Discolouration (2)
	42 Hot/dry Climate	16.6	250	9.0	14.9	-	86	Discolouration (1)
	180° Hot/dry JTRU	13.5	290	6.0	10.7	-	81	

Out of doors  
6 months  
12 months  
21.1

21.3

TABLE 3 (contd)

Elastomer Type	Type of Exposure and Duration (Days)	Tensile Strength (kg/cm <sup>2</sup> )	Extension at Break (per cent)	Modulus (kg/cm <sup>2</sup> ) at extension of			Hardness (BSO)	Visual assessments Major type of failure (0) = no change (4) = severe change
				100 (per cent)	200 (per cent)	300 (per cent)		
Hypalon HB (Black)	Control (not exposed)	17.8	360	3.5	10.4	15.7	64	
	21 Hot/wet Climatest	16.6	265	6.6	12.8	-	84	(0)
	42 Hot/wet Climatest	17.8	270	7.5	13.8	-	94	(0)
	180* Hot/wet cleared JTRU	18.7	225	10.7	17.2	-	90	Chalking (1)
	360** Temperate UK	18.4	265	7.9	14.5	-	79	
Polyester Urethane PU 1 (Black)	21 Hot/dry Climatest	21.9	250	8.9	18.4	-	82	(0)
	42 Hot/dry Climatest	21.5	240	9.6	18.6	-	85	(0)
	360* Hot/dry JTRU	18.7	270	6.8	14.2	-	79	
	Control (not exposed)	20.0	440	2.9	7.3	13.0	86	
	21 Hot/wet Climatest	18.8	415	2.9	7.2	12.9	89	(0)
Polyester Urethane PU 2 (Black)	42 Hot/wet Climatest	19.7	430	2.4	7.0	12.6	90	Colour (1)
	720*** Hot/wet cleared JTRU	14.8	365	2.7	6.8	11.4	94	Erosion (2) colour (1)
	Control (not exposed)	15.8	540	2.1	7.2	10.5	70	
	21 Hot/wet Climatest	12.3	500	2.2	6.9	11.9	68	(0)
	42 Hot/wet Climatest	16.4	510	1.6	5.9	10.7	68	(0)
Polyester Urethane PU 3 clear containing 4% polycarbodiimide	1500**** Hot/wet JTRU	4.0	400	1.6	5.4	7.0	63	Erosion (2) colour (1)
	Control (not exposed)	15.3	530	1.9	2.4	3.7	95	Colour (3)
	21 Hot/wet Climatest	7.1	740	0.2	0.6	1.0	40	Colour (3) surface tack (2)
	42 Hot/wet Climatest	4.6	8.0	0.1	0.4	0.6	40	Colour (3) erosion (2) surface tack (3)
	720*** Hot/wet cleared JTRU	2.3	400	-	-	-	71	

Out of doors  
 \*6 months  
 \*\*12 months  
 \*\*\*2 years  
 \*\*\*\*4 years  
 22.1

22.2

22.3

TABLE 4

OUTDOOR AND ACCELERATED WEATHERING OF  
GLASS REINFORCED POLYPROPYLENE THERMOPLASTICS

Type Number	Type		Type of Exposure (Days)	Tensile Strength (PSI/m <sup>2</sup> )		Extension at Break (per cent)		Tensile Modulus (PSI/m <sup>2</sup> x 10 <sup>-4</sup> )		Major Type of Visual Breakdown (0) = no change (4) = severe change
	Polypropylene (%)	Glass (%)		Range of Values	Mean	Range of Values	Mean	Range of Values	Mean	
1	PXC 8639 (60)	MSS 1607 (40)	None	Control (not exposed) 21 Hot/dry Climate 42 Hot/dry Climate 21 Hot/wet Climate 42 Hot/wet Climate 90° Temperature UK 180° Temperature UK	88.6-91.4 39.6-41.5 37.0 47.6-49.2 32.8-35.0 52.1-55.5 39.0-43.2 40.6	89.9 40.4 37.0 48.1 33.9 53.2 40.6	1.4-1.5 0.5-0.65 0.4-0.6 0.7-0.9 0.6-0.7 0.6-1.0 NR	9.8-10.4 7.0-9.0 5.7-8.2 9.7-10.2 7.0-7.7 6.0-9.0 NR	10.1 6.9 7.7 9.9 7.4 7.9	erosion (3) erosion (4) erosion (2) erosion (4) erosion (0) erosion (1)
2	PXC 8639 (60)	MSS 1613 (40)	None	Control (not exposed) 21 Hot/dry Climate 42 Hot/dry Climate 21 Hot/wet Climate 42 Hot/wet Climate 90° Temperature UK 180° Temperature UK	88.0-90.2 50.0-53.8 27.4-36.1 32.1 54.0-57.0 33.3-40.7 118.0-130.0 47.2-52.2 48.5	88.6 51.6 32.1 55.3 38.1 122.2 48.5	1.9-2.3 0.4-1.0 0.4-0.9 1.0-1.9 0.7-1.0 1.0-1.05 NR	5.7-6.4 6.6-8.9 6.7-9.1 7.3-10.7 4.8-7.0 3.3-3.6 NR	6.1 7.6 7.9 6.0 6.0 3.5	erosion (3) erosion (4) erosion (3) erosion (4) erosion (0) erosion (1)
3	PXC 8639 (60)	MSS 1607 (40)	Carbon Black (1.5)	Control (not exposed) 21 Hot/dry Climate 42 Hot/dry Climate 21 Hot/wet Climate 42 Hot/wet Climate 90° Temperature UK 180° Temperature UK	81.0-97.8 84.0-98.0 87.6 84.0-89.0 86.8 80.5-89.0 83.4-86.6 82.1-91.0 86.9 8.4-99.1 85.7	87.4 87.6 81.8 86.8 80.9 83.7 86.9 85.7	1.4-2.0 1.6-2.0 1.4-1.7 1.4-1.9 1.5 1.4-1.8 1.6-1.8 NR	6.0-10.3 7.0-8.7 7.4-9.2 7.3-9.0 7.7-8.5 7.4-9.3 NR	8.3 7.7 8.2 8.1 8.1 8.2	erosion (1) erosion (3) erosion (1) erosion (1) water spotting (3) water spotting (3) water spotting (3) white deposit (3) erosion (0)
4	PXC 8639 (60)	MSS 1613 (40)	Carbon Black (1.5)	Control (not exposed) 21 Hot/dry Climate 42 Hot/dry Climate 21 Hot/wet Climate 42 Hot/wet Climate 90° Temperature UK 180° Temperature UK	36.5-86.2 79.0-84.7 81.4 75.9-84.7 80.9 79.7-83.6 70.1-80.4 66.3-81.8 60.0-83.2 79.0	74.7 81.4 80.9 77.4 78.1 79.0	1.4-2.5 1.4-1.7 1.6 1.6-1.9 1.7 1.5-1.9 1.6 1.6-2.1 NR	5.3-8.7 6.5-8.3 6.4-8.2 6.5-8.2 7.6 7.6-11.0 4.6-7.4 NR	6.5 7.4 7.6 7.5 8.9 6.6	erosion (1) erosion (2) water spotting (3) white deposit (3) erosion (0)
5	PXC 8639 (60)	MSS 1607 (40)	Oil Nigrosine (0.5)	Control (not exposed) 21 Hot/dry Climate 42 Hot/dry Climate 21 Hot/wet Climate 42 Hot/wet Climate 90° Temperature UK 180° Temperature UK	31.4-88.0 75.0-81.7 77.9 66.0-72.5 69.4 73.5-77.8 65.9 69.9-74.9 73.2 71.8-73.7 72.5	83.9 77.9 69.4 75.4 65.9 73.2 72.5	1.6-1.8 1.3-1.5 1.4 1.2-1.4 1.3 1.3-1.5 1.1 1.3-1.4 NR	6.6-7.7 6.0-9.1 7.1-8.2 7.9-9.0 8.4 9.0-12.1 6.9-7.5 NR	7.1 7.6 7.5 8.4 8.7 7.6	erosion (3) erosion (4) erosion (3) erosion (4) erosion (1) erosion (2)
6	PXC 8639 (60)	MSS 1613 (40)	Oil Nigrosine (0.5)	Control (not exposed) 21 Hot/dry Climate 42 Hot/dry Climate 21 Hot/wet Climate 42 Hot/wet Climate 90° Temperature UK 180° Temperature UK	85.0-91.5 75.0-89.4 78.6 64.0-69.1 67.6 76.3-80.0 78.0 58.7-75.0 68.6 73.6-77.9 74.9 72.3-74.6 73.1	87.6 78.6 67.6 78.0 68.6 74.9 73.1	1.6-1.9 1.3-1.55 1.5 1.1-1.5 1.3 1.6-1.9 1.4 1.4-1.6 NR	7.7-9.1 10.0-13.6 6.6-9.7 7.7 7.1-8.2 7.3-10.0 7.0-7.9 NR	8.1 11.8 7.7 7.7 8.0 7.4	erosion (3) erosion (4) erosion (3) erosion (4) erosion (1) erosion (2)

23.1  
NR not recorded

\* Out of doors 3 months

\*\* Out of doors 6 months

TABLE 5

## OUTDOOR AND ACCELERATED WEATHERING OF NATURAL ACETAL COPOLYMER

Type of Exposure	Duration of Exposure (Days)	Rate and Method of Test (mm/min)	Initial Properties		Percentage Change of Original Mechanical Property		Visual Assessment (0) = no change (4) = severe change
			Tensile Strength (kg/cm <sup>2</sup> )	Extension at Break (per cent)	Tensile Strength	Extension at Break	
LWA Solar radiation concentrating device HCT/ARY ARIZONA	0 (unexposed control)	Hounsfield Type E 25 mm/min	63.6	4.8	-3.5	-37.5	(0)
	7				-8.5	-52.0	(0)
	14				-18.5	-66.5	gloss (1) chalking (1)
	28				-46.5	-69.0	gloss (4) chalking (4) cracking (3)*
	56				-86.5	-89.0	gloss (4) chalking (4) cracking (4)*
LWA HCT/ARY ARIZONA	112						
	0 (unexposed control)	Hounsfield Type E 25 mm/min	63.6	4.8	-41.0	-83.5	gloss (1) chalking (1)
	91				-44.5	-81.0	gloss (4) chalking (4) colour (1) cracking (1)*
	182				-62.5	-75.0	gloss (4) chalking (4) colour (2) cracking (4)*
JHU TROPICAL HCT/ARY	0 (unexposed control)	Denison T42U 5 mm/min	60.9	31.0	-17.0	-68.0	chalking (1) colour (2) erosion (2)
	100				-24.0	-74.0	chalking (4) colour (2) erosion (4) cracking (1)
	175				-24.5	-64.5	chalking (1) colour (2) erosion (4) cracking (1)
	350				-30.5	-80.5	chalking (4) colour (2) erosion (4) cracking (3)
	700				-49.0	-87.0	chalking (4) colour (2) erosion (4) cracking (3)
	1050						
CLIMATE HCT/ARY	0 (unexposed control)	Hounsfield Type E 25 mm/min	56.1	26.1	-13.0	-83.0	colour (1)
	21				-16.0	-83.0	gloss (3) colour (3) chalking (4) [adherent white deposit]
	42						
JHU TROPICAL HCT/ARY	0 (unexposed control)	Denison T42U 5 mm/min	60.9	31.0	-37.0	-87.0	colour (1) cracking (1)
	100				-63.5	-93.5	colour (2) chalking (1) erosion (1) cracking (1)
	175				-64.5	-93.5	colour (2) chalking (1) erosion (2) cracking (1)
	350				-57.5	-90.5	colour (3) erosion (2) cracking (3)
	700				-57.5	-93.5	colour (3) erosion (4) cracking (3)
	1050						
UW TROPICAL HCT/ARY	0 (unexposed control)	Hounsfield Type E 5 mm/min	64.6	58.0	-7.5	-53.5	
	100				+11.0	-69.0	
	175				-10.5	-65.5	
	350				-18.0	-88.0	
	1050				-45.0	-93.0	
CLIMATE HCT/ARY	0 (unexposed control)	Hounsfield Type E 25 mm/min	56.1	26.1	-47.0	-95.5	colour (1) chalking (1)
	21				-26.5	-90.0	gloss (3) colour (3) chalking (4) [adherent white deposit]
	42						

\* at notches of notched tensile specimens only (Ref 22)

TABLE 6

## OUTDOOR AND ACCELERATED WEATHERING OF NATURAL CHLORINATED POLYETHER 'PEMTON'

Duration and Type of Exposure (Days)	Tensile Properties				Percentage Change of Original Mechanical Property				Visual Assessment (0) = no change (4) = severe change
	At yield		At break		At yield		At break		
	Strength (N/m <sup>2</sup> )	Extension (per cent)	Strength (N/m <sup>2</sup> )	Extension (per cent)	Strength	Extension	Strength	Extension	
*Control (not exposed) Climate test	38.9	13.8	27.3	121.5	-	-	-	-	-
*21 Hot/dry Climate test	-	-	-	-	no yield	no yield	-38.8	-77.7	colour (3)
*42 Hot/wet Climate test	-	-	-	-	-44.0	+63.0	+1.5	-68.0	colour (3)
**Control (not exposed) JTRU	37.0	40.0	27.1	300.0	-	-	-	-	-
**90 Hot/wet cleared JTRU	-	-	-	-	+0.5	-7.5	-17.4	-58.0	(0)
**180 Hot/dry cleared JTRU	-	-	-	-	0.0	+12.5	-18.9	-76.0	(0)
**360 Hot/dry cleared JTRU	-	-	-	-	0.0	+10.0	-22.9	-81.5	chalking (4) erosion (4)
**720 Hot/dry cleared JTRU	-	-	-	-	no yield	no yield	+32.0	-78.0	chalking (4) erosion (4)
Control (not exposed) Climate test	38.9	13.8	27.3	121.5	-	-	-	-	-
*21 Hot/dry Climate test	-	-	-	-	no yield	no yield	+45.7	-77.3	colour (2)
*42 Hot/dry Climate test	-	-	-	-	no yield	no yield	+50.2	-88.0	colour (3)
**Control (not exposed) JTRU	37.0	40.0	27.1	300.0	-	-	-	-	-
**90 Hot/dry JTRU	-	-	-	-	-1.1	-7.5	-11.5	-64.4	(0)
**180 Hot/dry JTRU	-	-	-	-	-3.8	+17.5	-20.7	-77.4	colour (2)
**360 Hot/dry JTRU	-	-	-	-	no yield	no yield	+38.7	-83.4	chalking (3) erosion (4)
**720 Hot/dry JTRU	-	-	-	-	no yield	no yield	+34.0	-82.7	chalking (3) erosion (4)

\*Tested at rate of stressing of 25.0 mm/min using Hounsfield Type E Tensometer  
 \*\*Tested at rate of stressing of 12.5 mm/min using Denison T42U Tensile Testing Machine

45.1

S No 59/72/CC

25.2

25.3

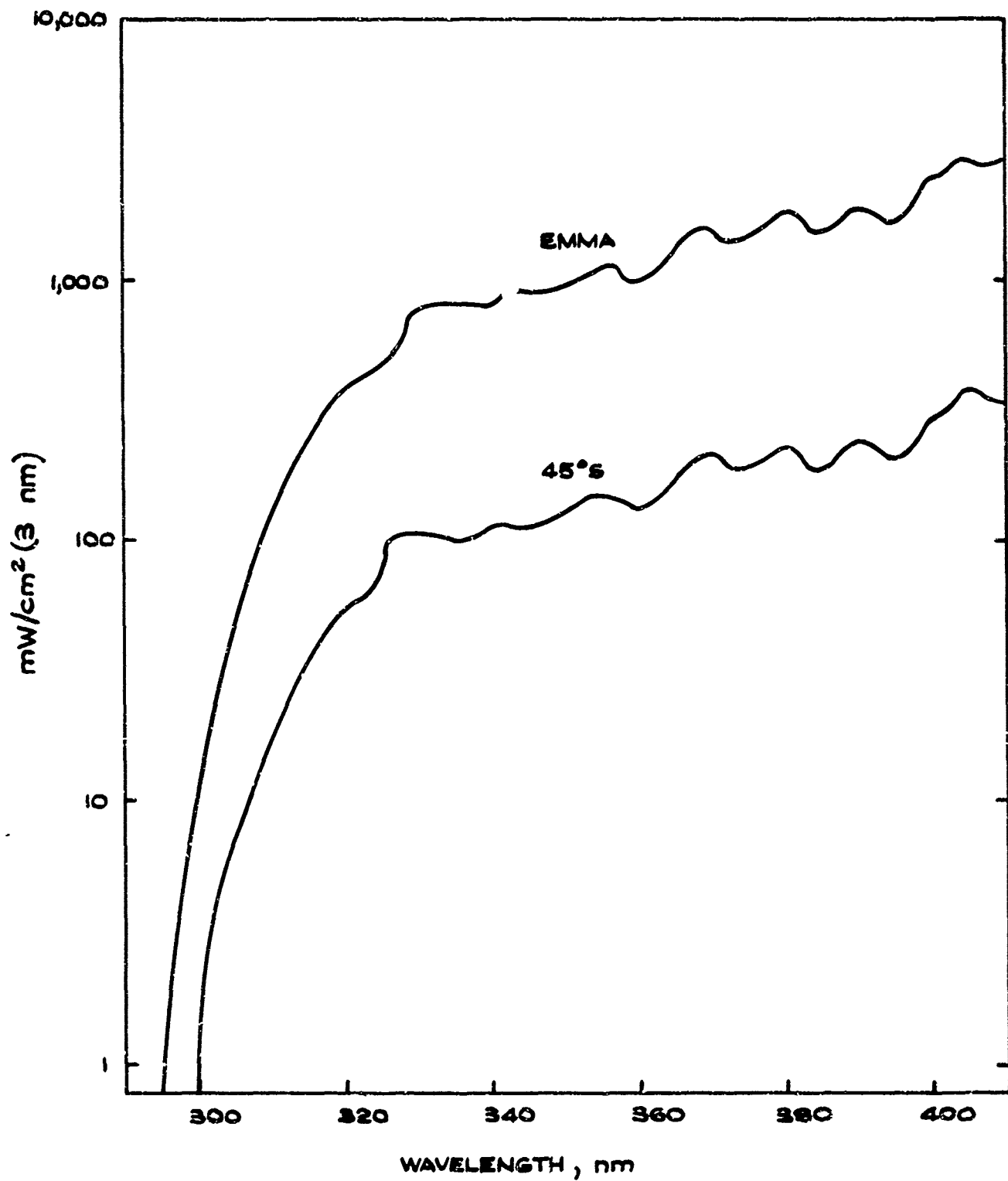


FIG. 1 COMPARISON OF ULTRAVIOLET ENERGY SPECTRA OF DIRECT  
SUNLIGHT AT 45° SOUTH AND IN THE EMMA DEVICE

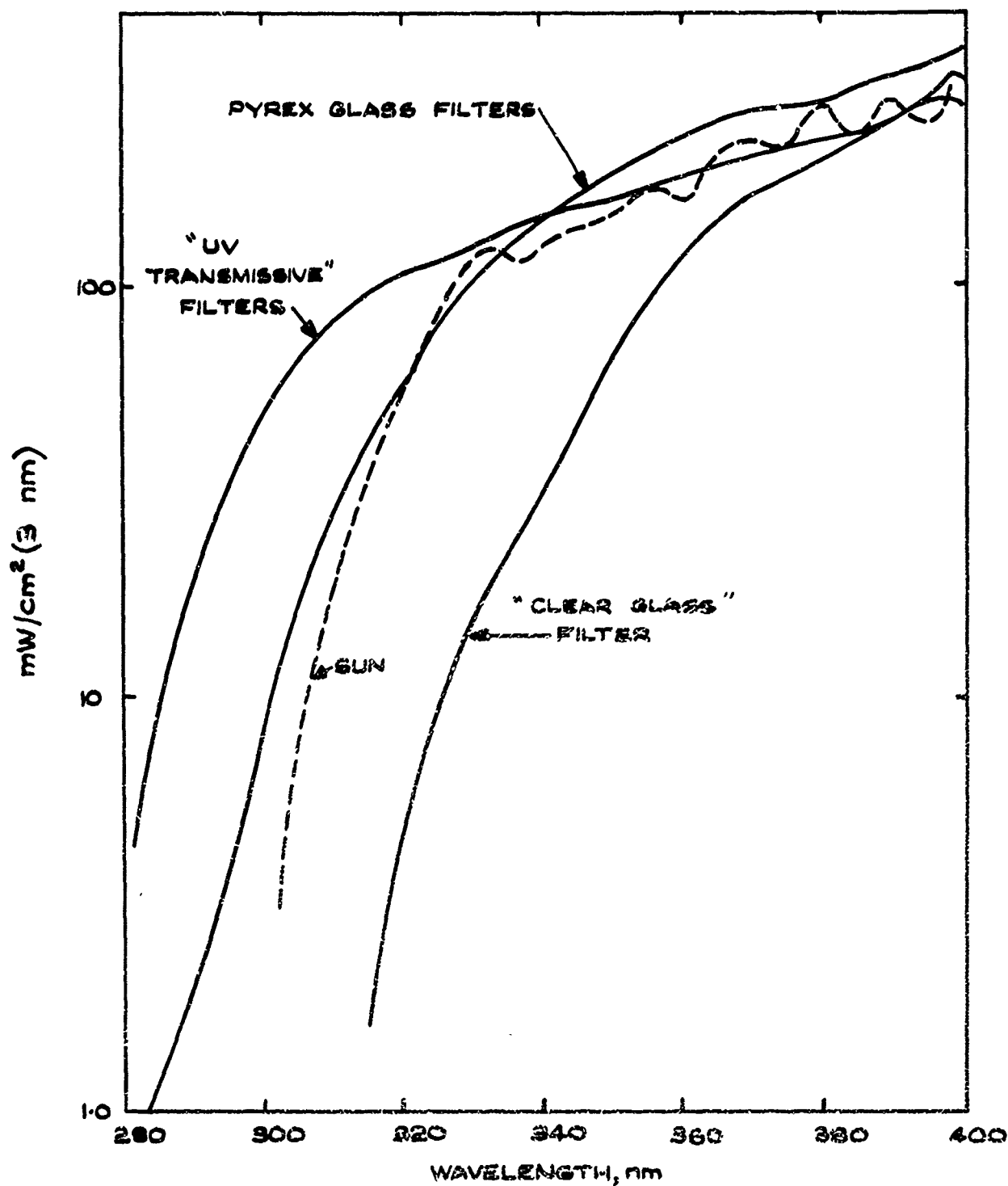


FIG.2 SPECTRAL ENERGY DISTRIBUTION OF 6000 W XENON ARC  
THROUGH VARIOUS TYPES OF FILTERS COMPARED WITH  
SUNLIGHT AT THE EARTH'S SURFACE

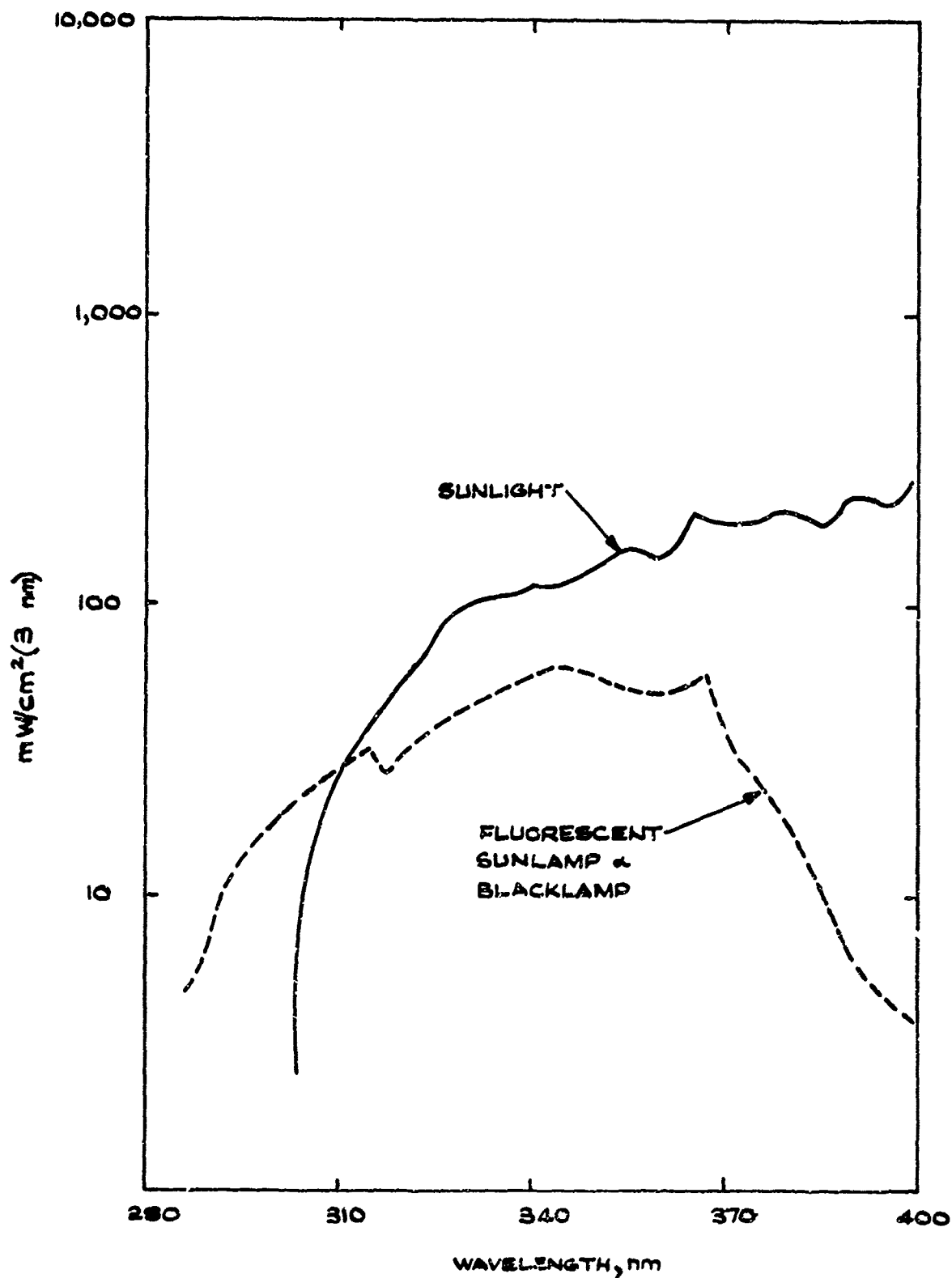


FIG. 3 COMBINATION OF FLUORESCENT SUNLAMP AND BLACKLAMP COMPARED WITH SUNLIGHT



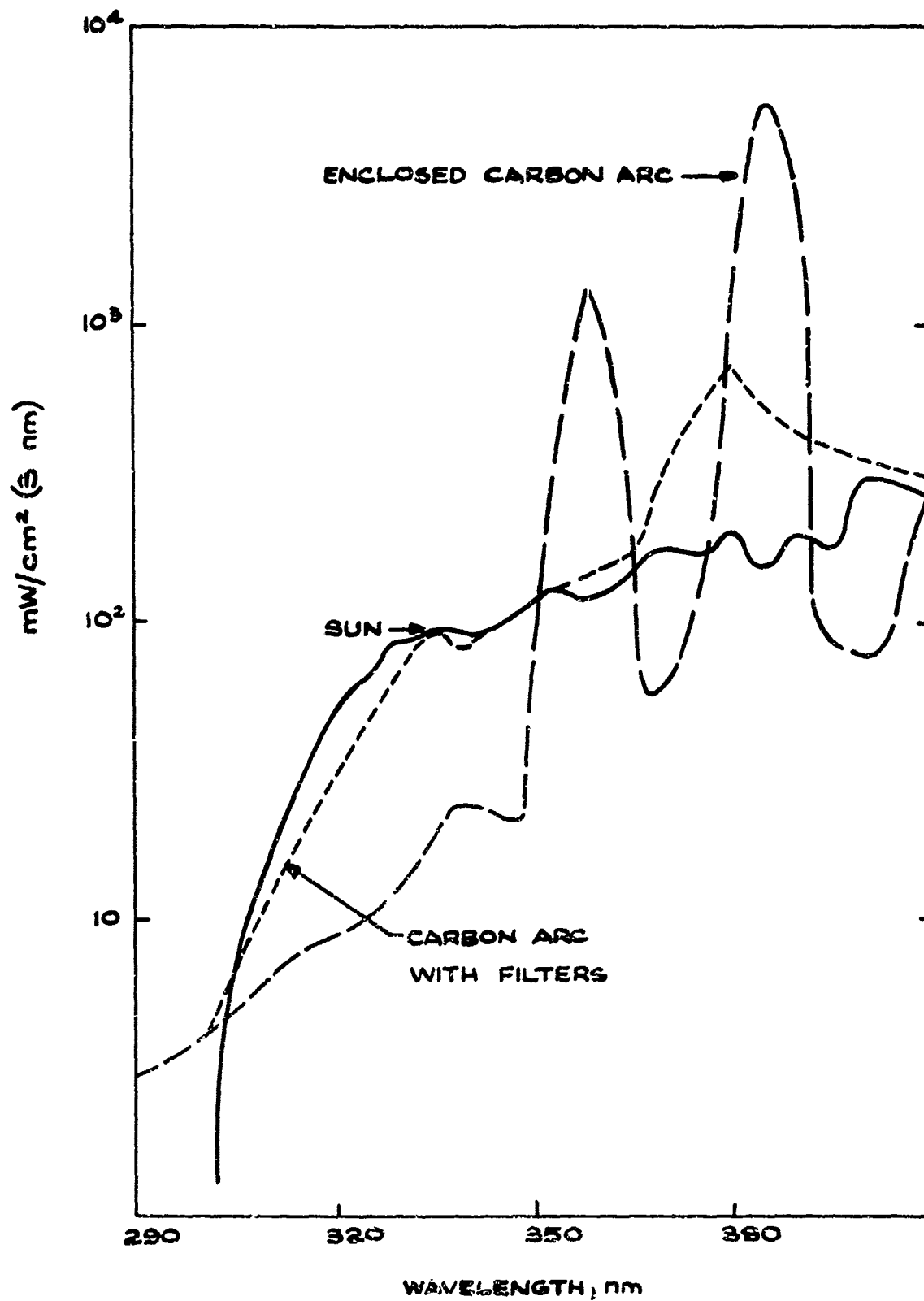


FIG. 4 ULTRAVIOLET SPECTRAL DISTRIBUTIONS OF ENCLOSED CARBON ARC AND SUNSHINE CARBON ARC COMPARED WITH SUNLIGHT

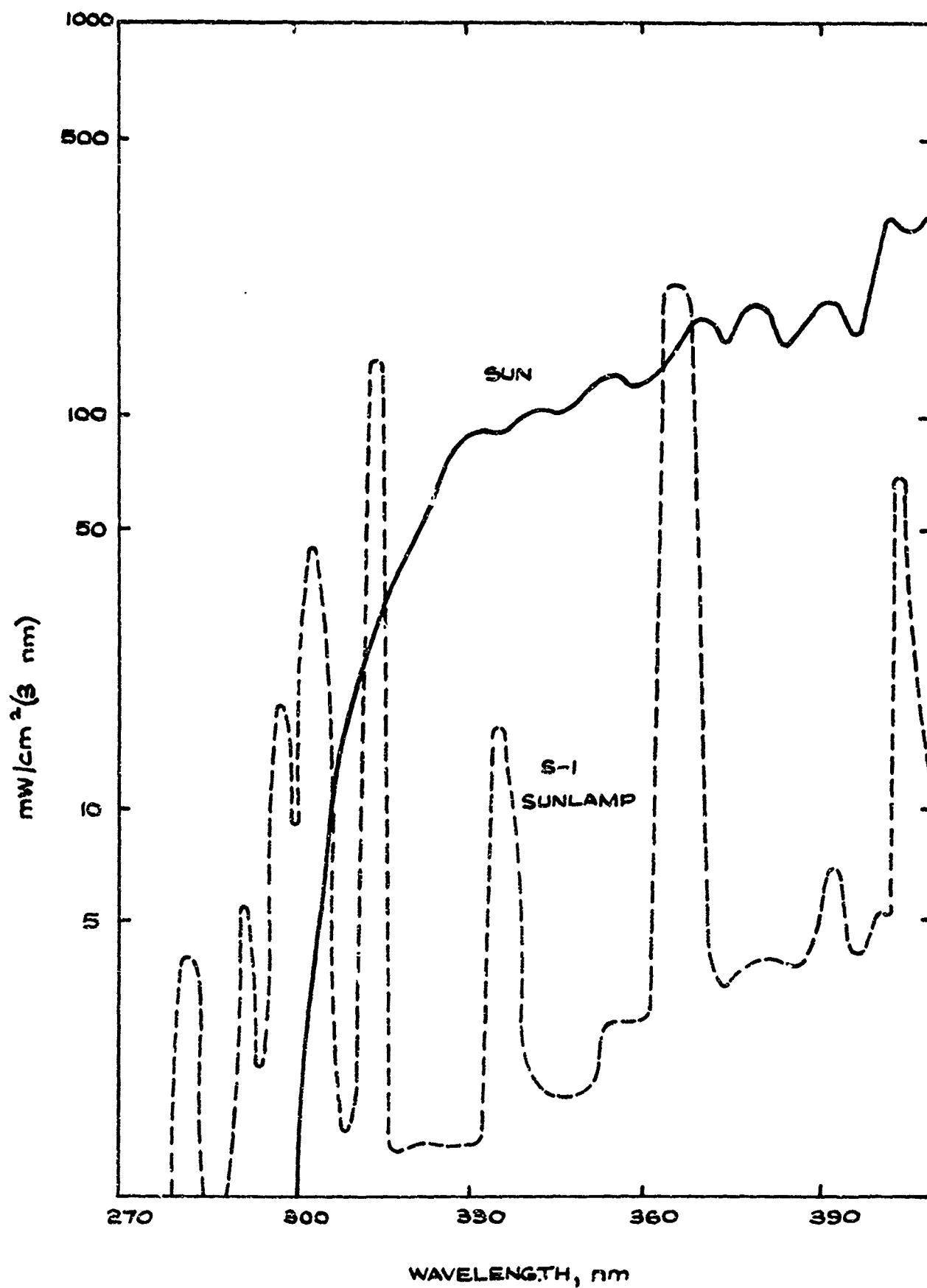


FIG. 5 SPECTRAL ENERGY DISTRIBUTION OF MERCURY VAPOUR LAMP COMPARED WITH SUNLIGHT

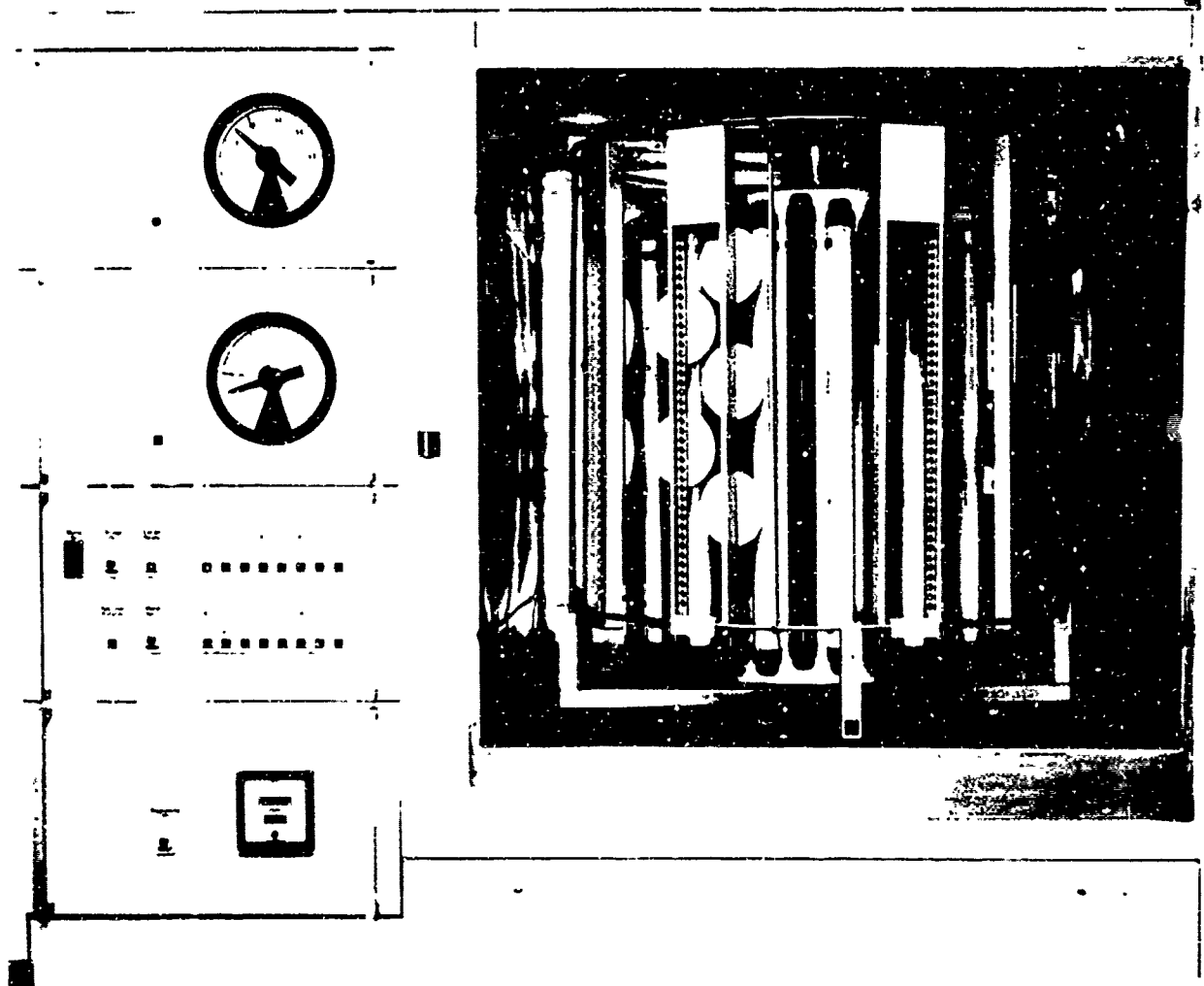



FIG. 6 'CLIMATEST' APPARATUS

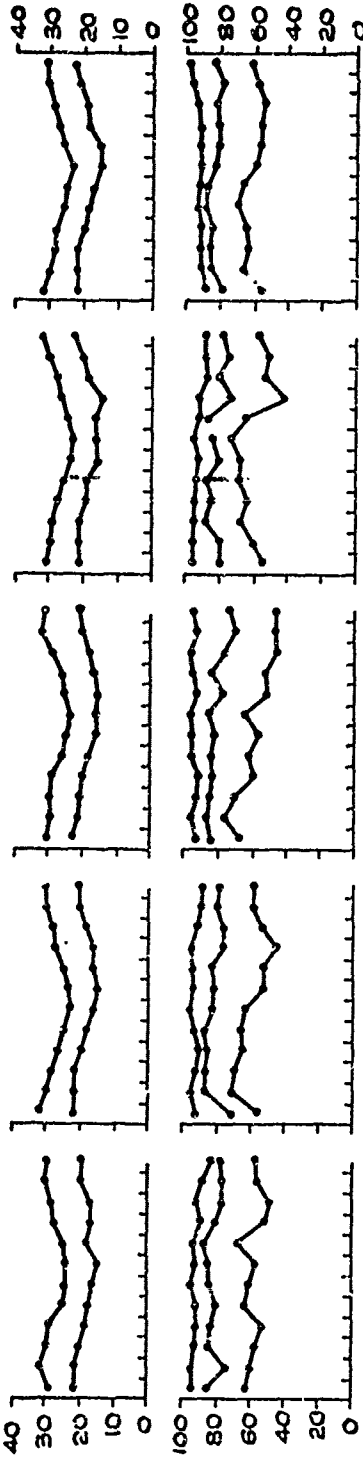
Reproduced from  
best available copy. 

# ERDE TR 107

## INNISFAIL (HOT/WET CLEARED)

### TEMPERATURE °C

Average daily maximum  
Average daily minimum

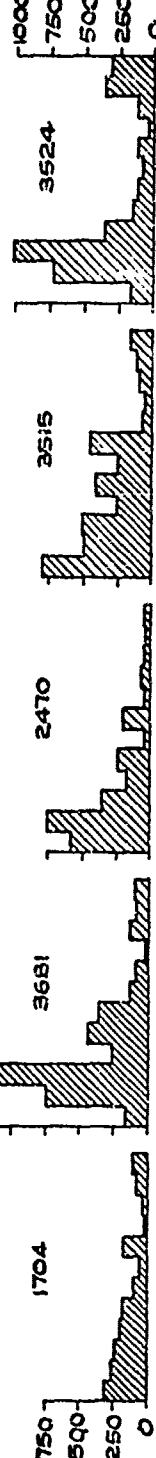


RELATIVE HUMIDITY %  
Average daily maximum  
Average index of mean RH.  
Average daily minimum

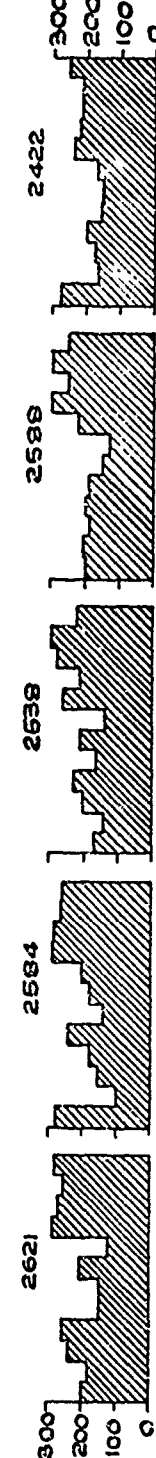
% time above 70%



RAINFALL (mm)  
(Figures denote annual totals)



SUN HOURS  
(CAMBELL-STOKES)  
(Figures denote annual totals)



RADIATION (MJ/m²)  
(MOLL-KIPP THERMOPILES)  
(Figures denote annual totals)

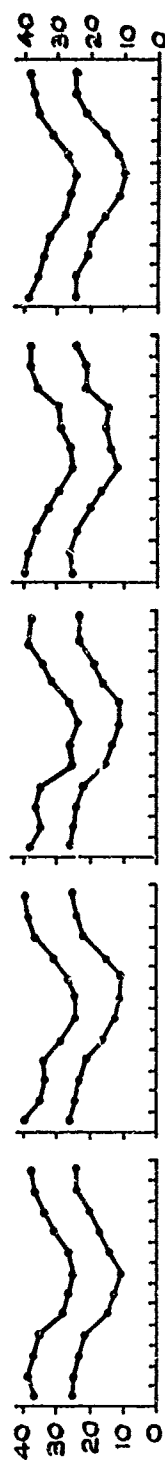


32.1

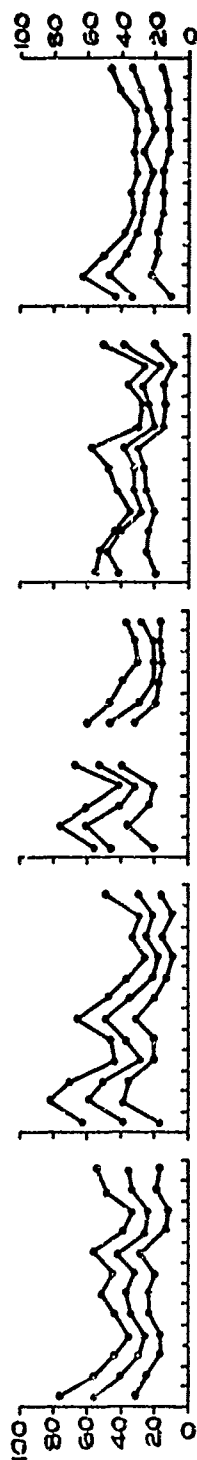
1966 1967 1968 1969 1970

FIG. 7-32.2

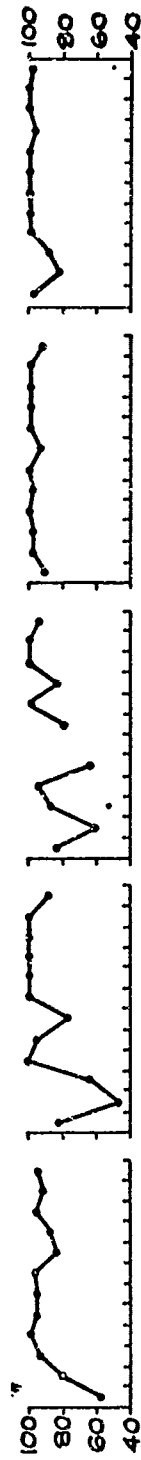
TEMPERATURE °C  
Average daily maximum  
Average daily minimum



RELATIVE HUMIDITY %  
Average daily maximum  
Average index of mean RH.  
Average daily minimum



% time below 60%



RAINFALL (mm)  
(figures denote annual totals)



SUN HOURS  
(CAMPBELL-STOKES)  
(figures denote annual totals)

